The Future with Cryogenic Fluid Dynamics

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- Definitions
- Natural convection in cryogenic systems
- Applications of CryoFD
- Some anecdotes on global uses
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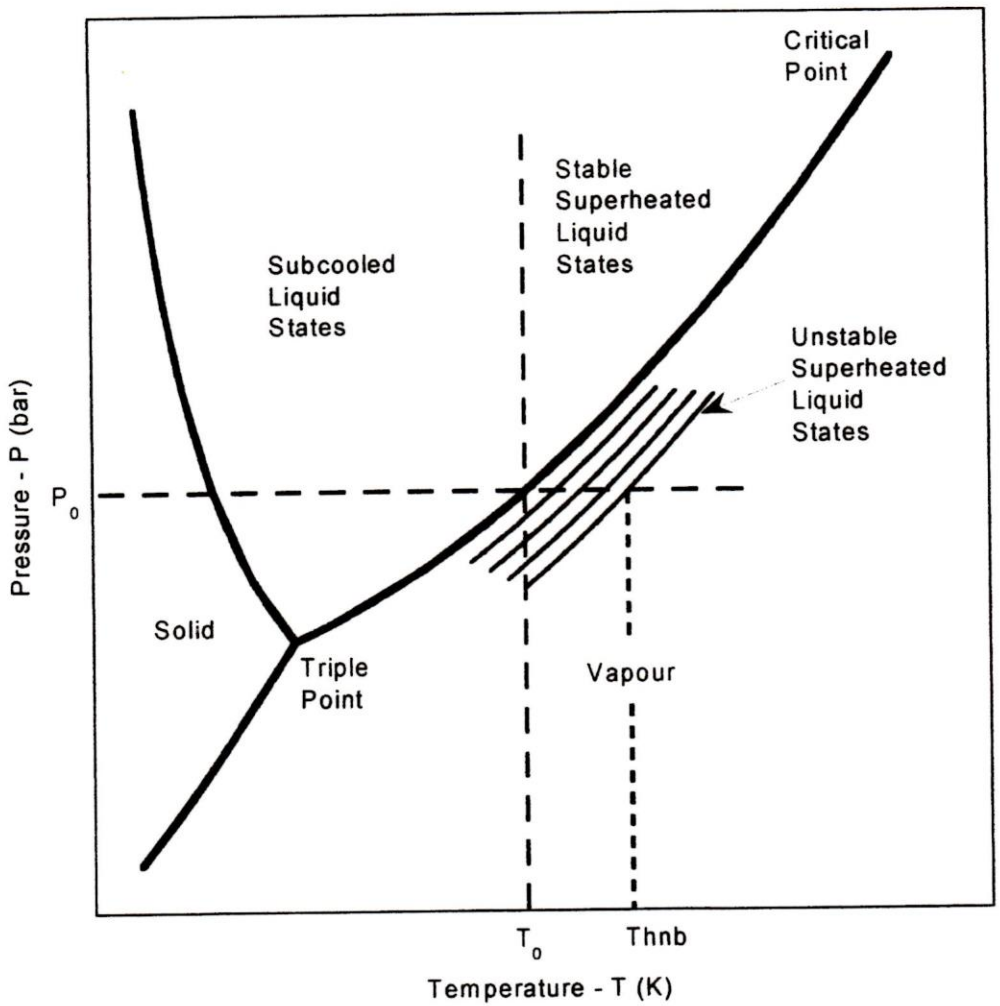
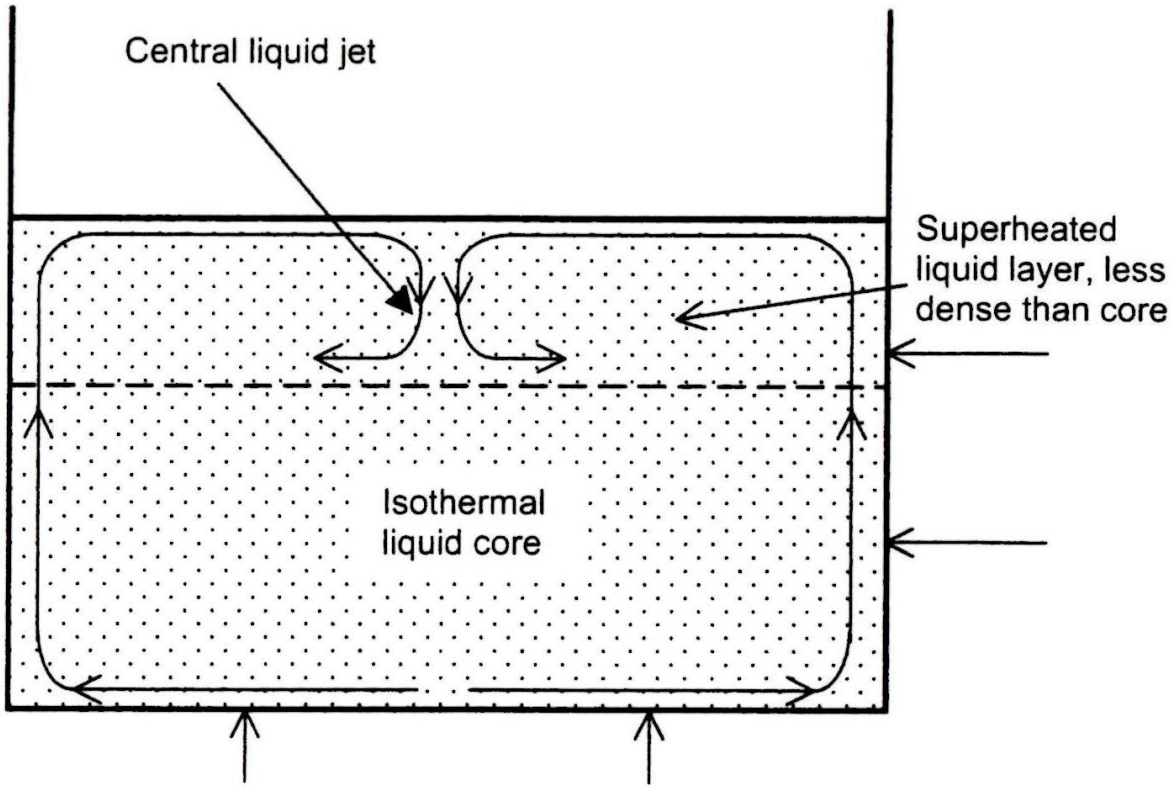
Cryogenic temperature range

- 1884 K.Onnes. **Cryogenic** Lab at Leiden.
- 1935 M.Ruhemann. Set 120K as limit.
- 1971 N.Kurti. Reset 120K, for **Cryology.**
- 1992 R.Scurlock. Proposed 273K.0ºC.
- 2011 R.Scurlock. Proposed 250K. -23ºC.

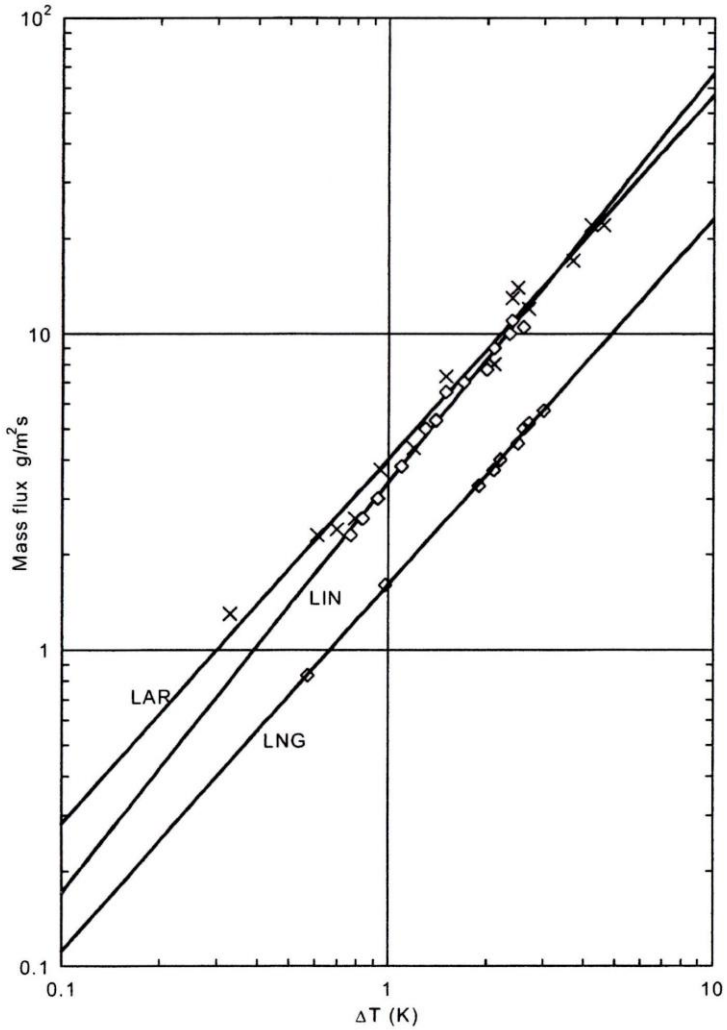


Typical P - T diagram showing equilibrium curves and thermodynamic states of subcooled and superheated liquid.
(Thnb = homogeneous nucleate boiling temperature)

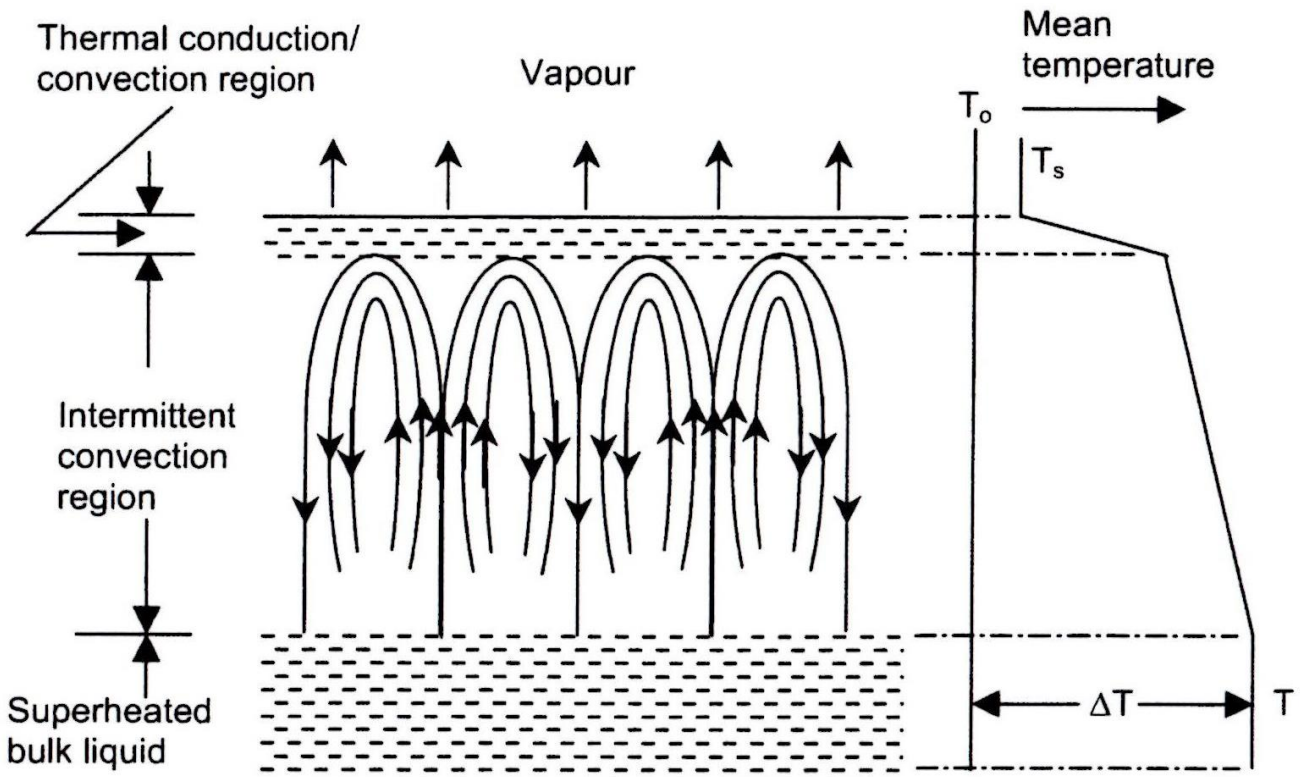
Open loop liquid convection circulation



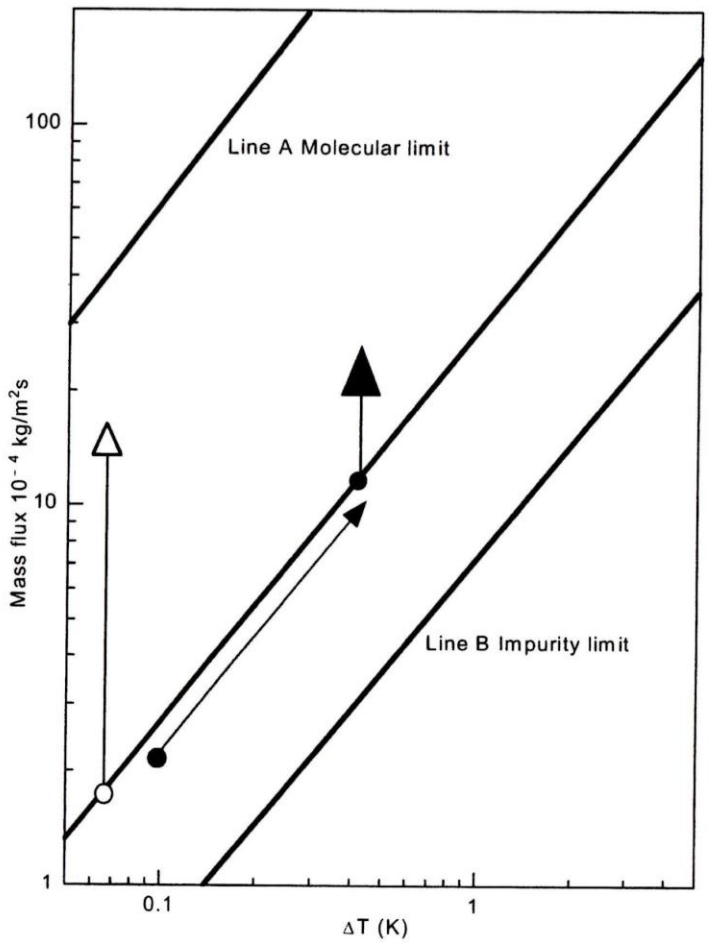
Surface evaporation mass flux vs. bulk superheat ΔT



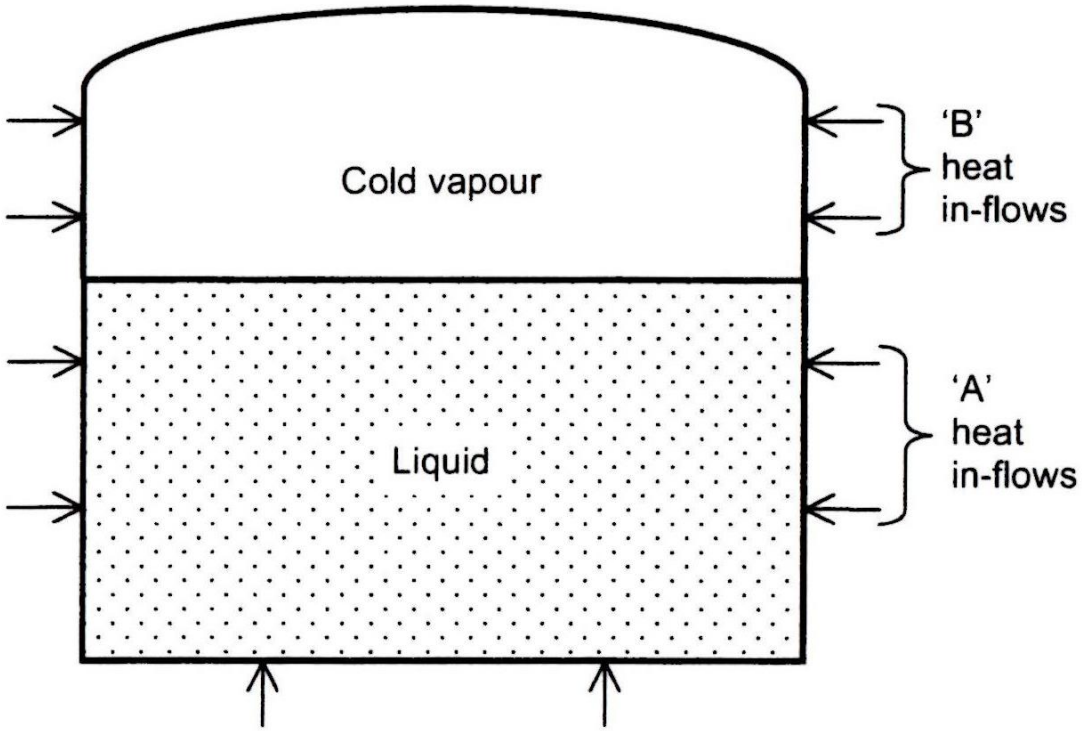
Morphology and temperature profile across evaporating surface sub-layer



Limits of surface evaporation mass flux vs. ΔT



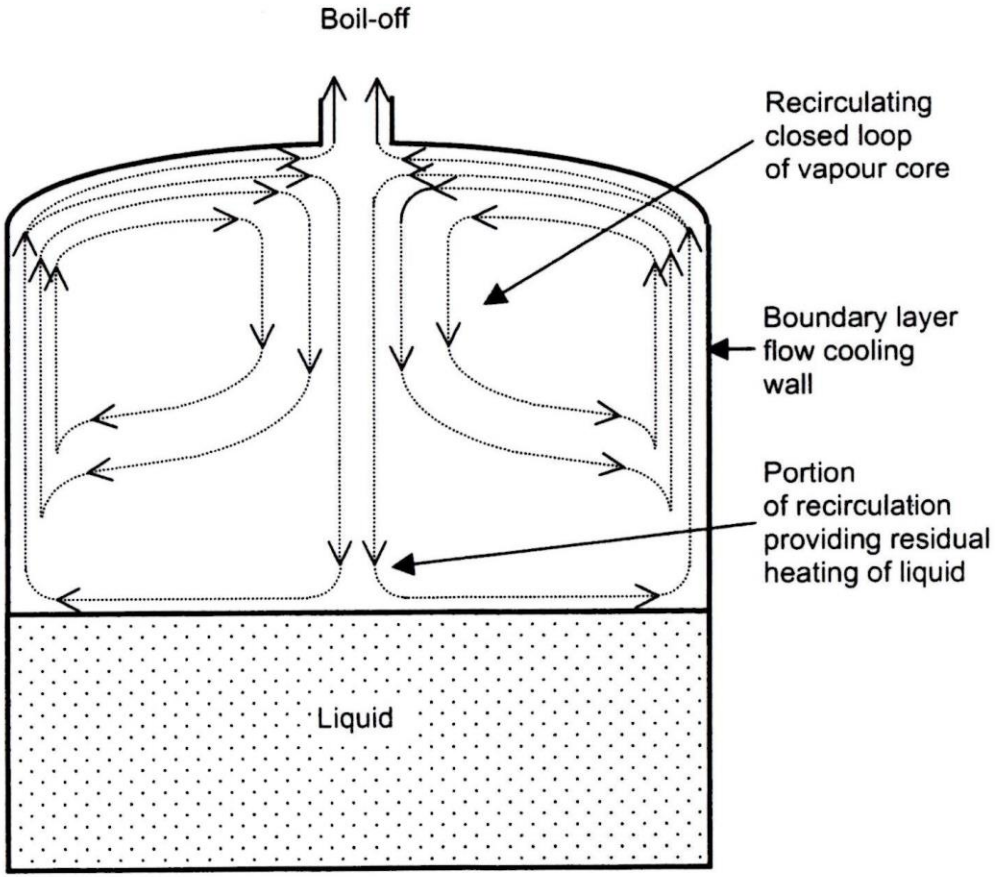
Distinction between A and B heat inflows



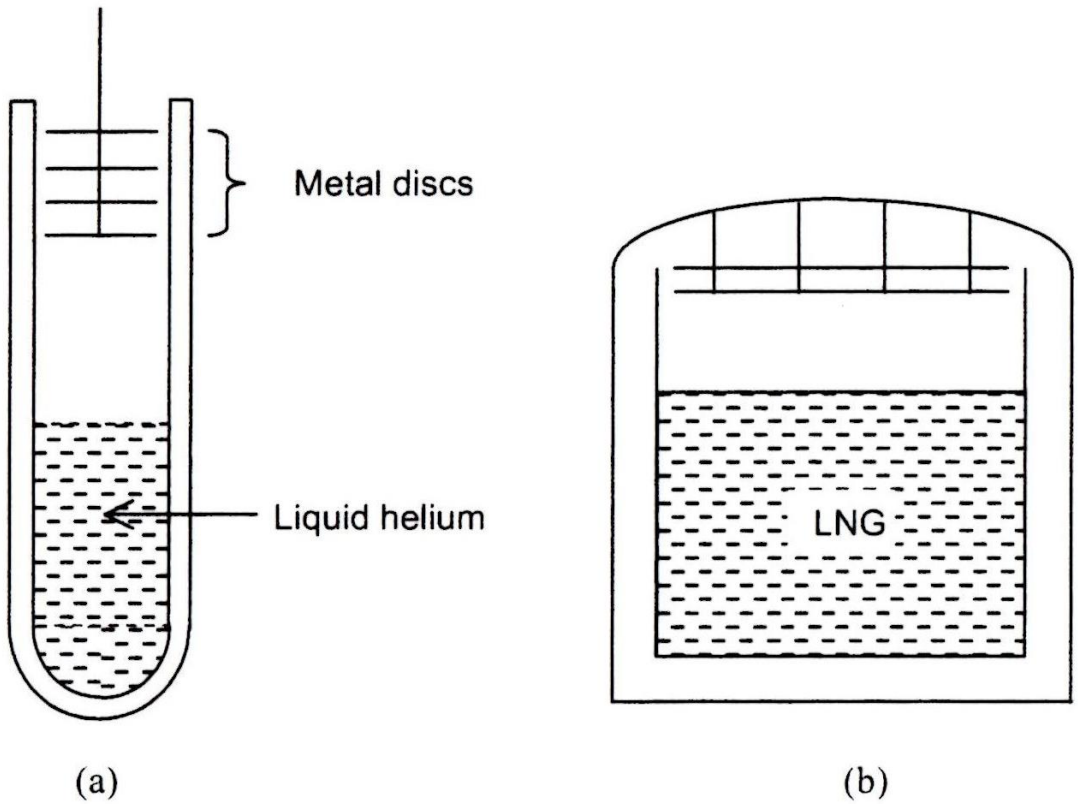
Sensible heat of vapour ΔH (from NBP to 300K) and Latent heat of evaporation λ

	λ kJ/kg	ΔH kJ/kg	ΔH/ λ
Helium 4	20.7	1564	75.5
Hydrogen	445	3511	7.9
Neon	85.7	283	3.3
Nitrogen	199	234	1.2
Oxygen	212	193	0.9
Methane	510	404	0.8

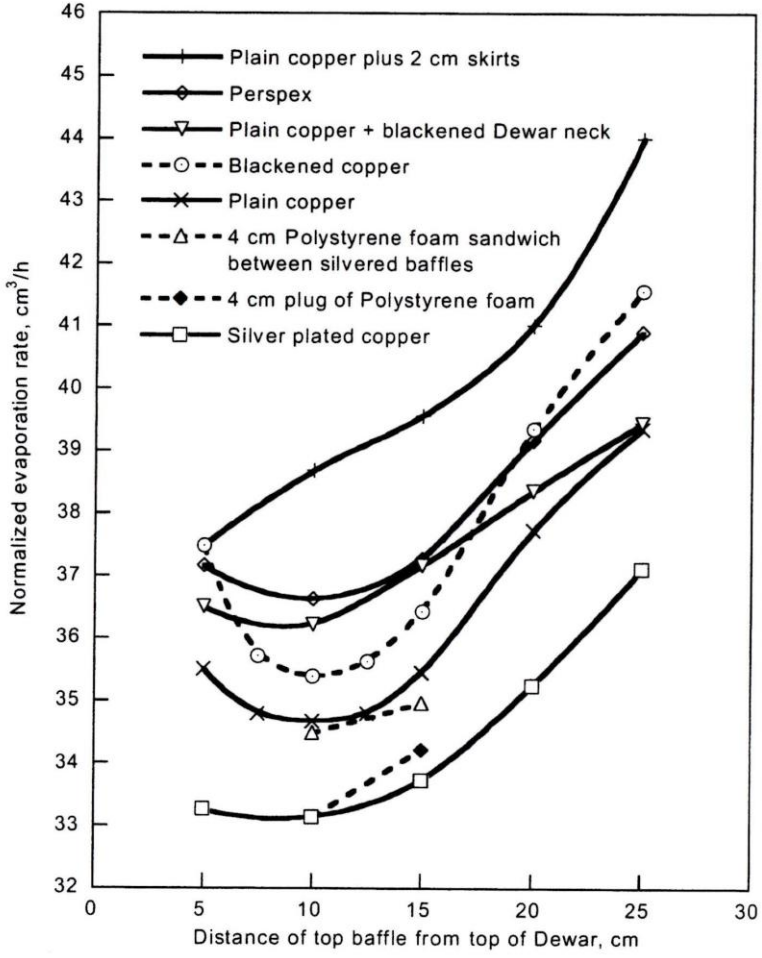
Vapour boundary layer flow and recirculation



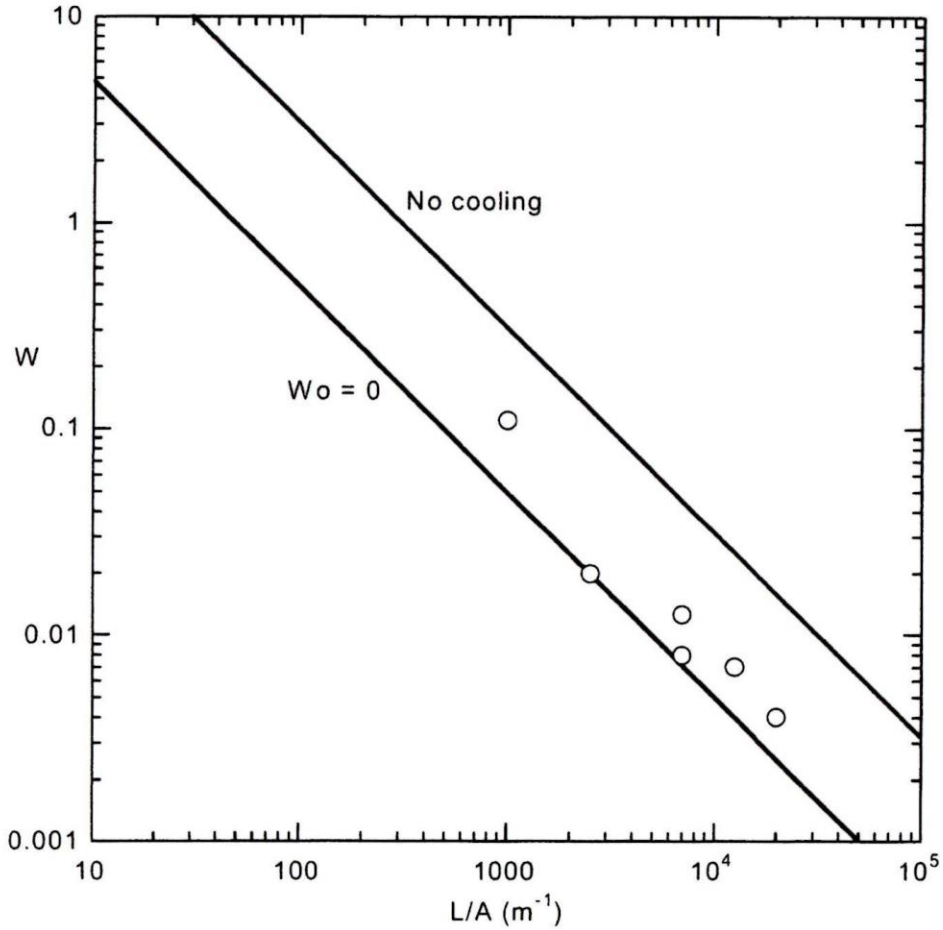
Vapour cooled shields. (a) LHe dewar (b) LNG storage tank



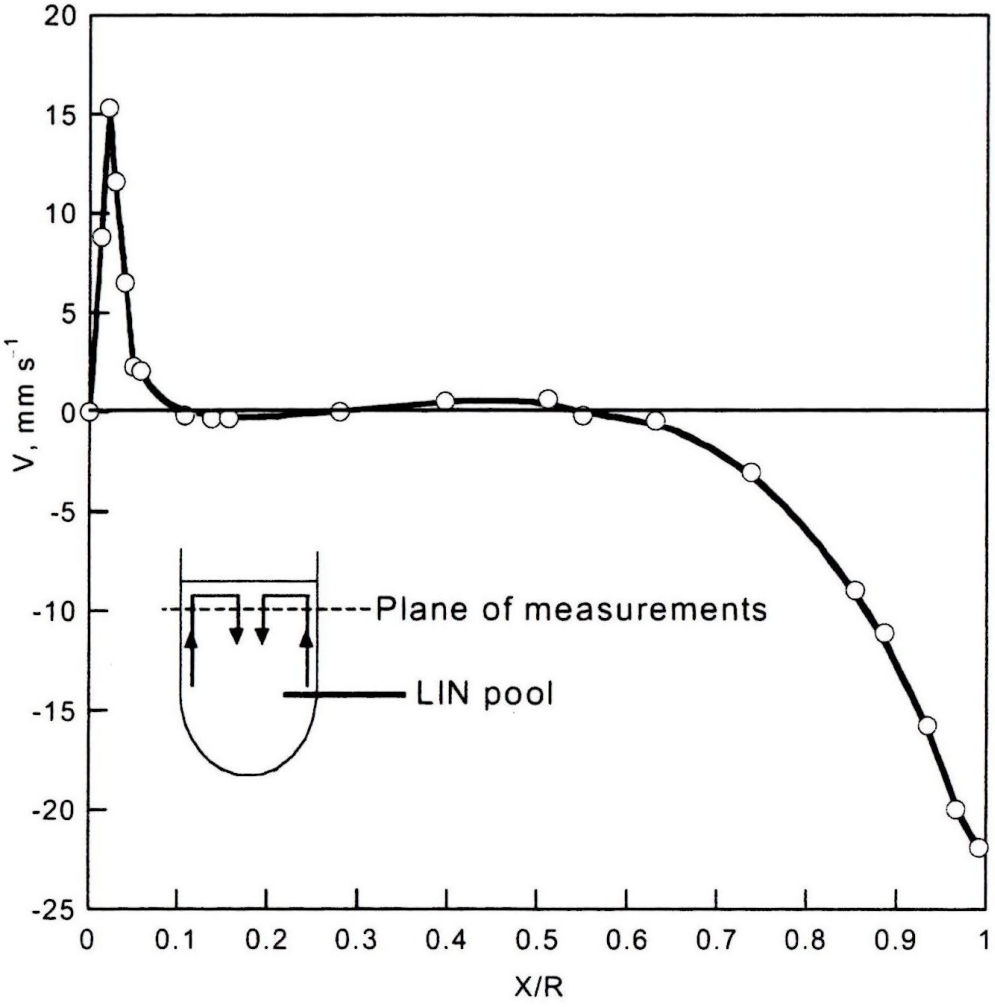
Vapour cooled shields. Variation of helium boil-off with position



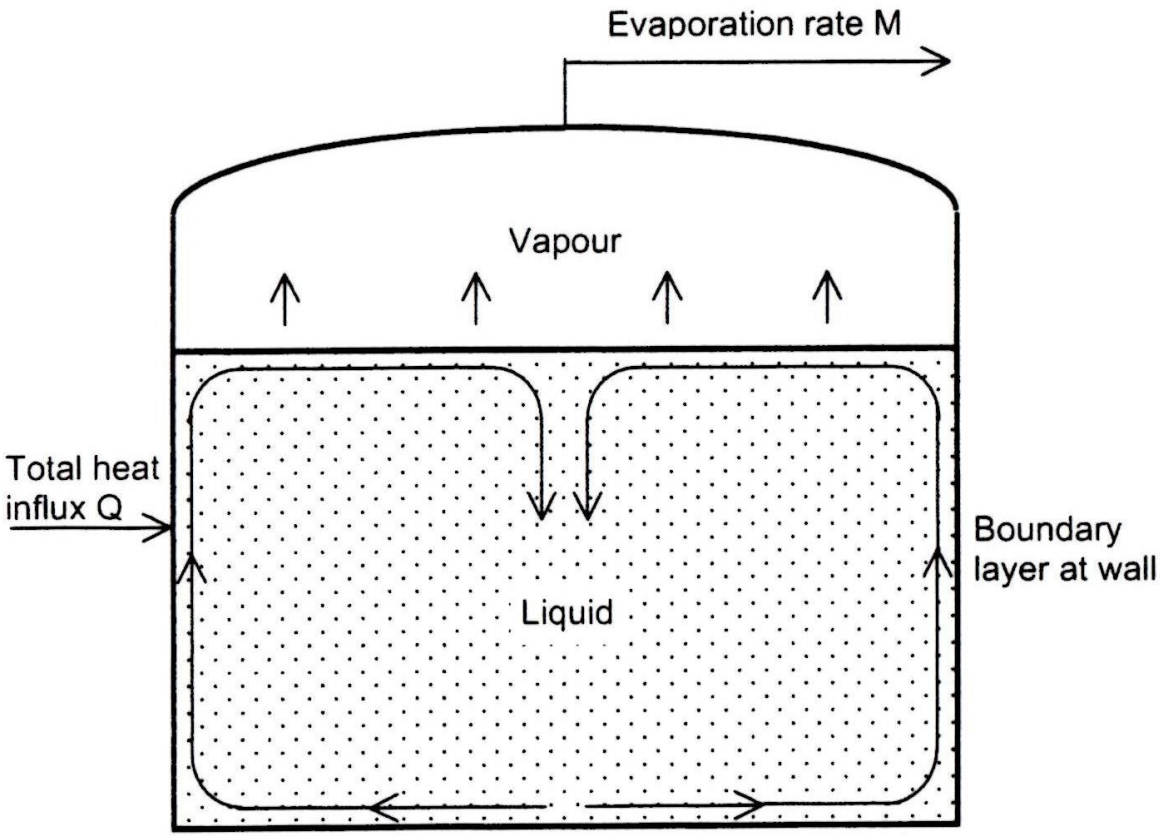
Design diagram for minimum helium boil-off



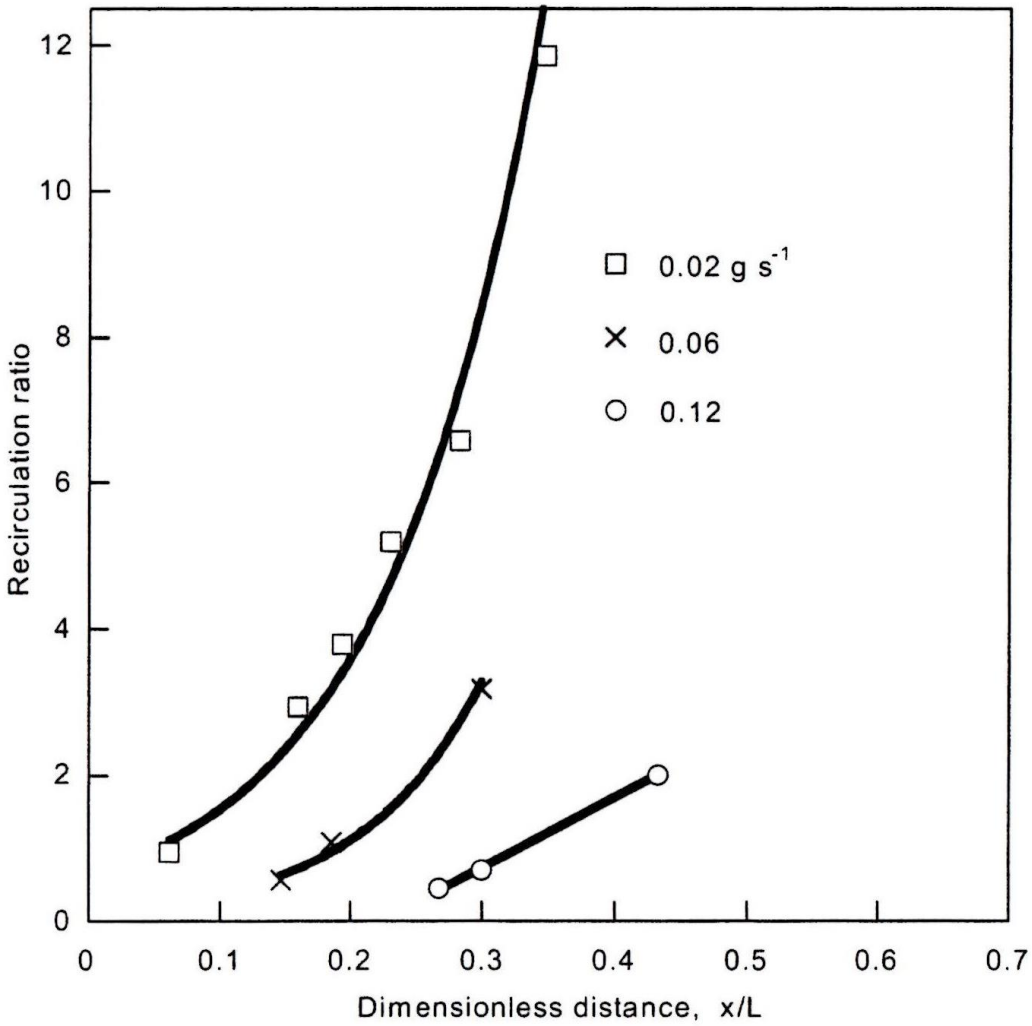
Laser Doppler Velocity diagram of liquid recirculation



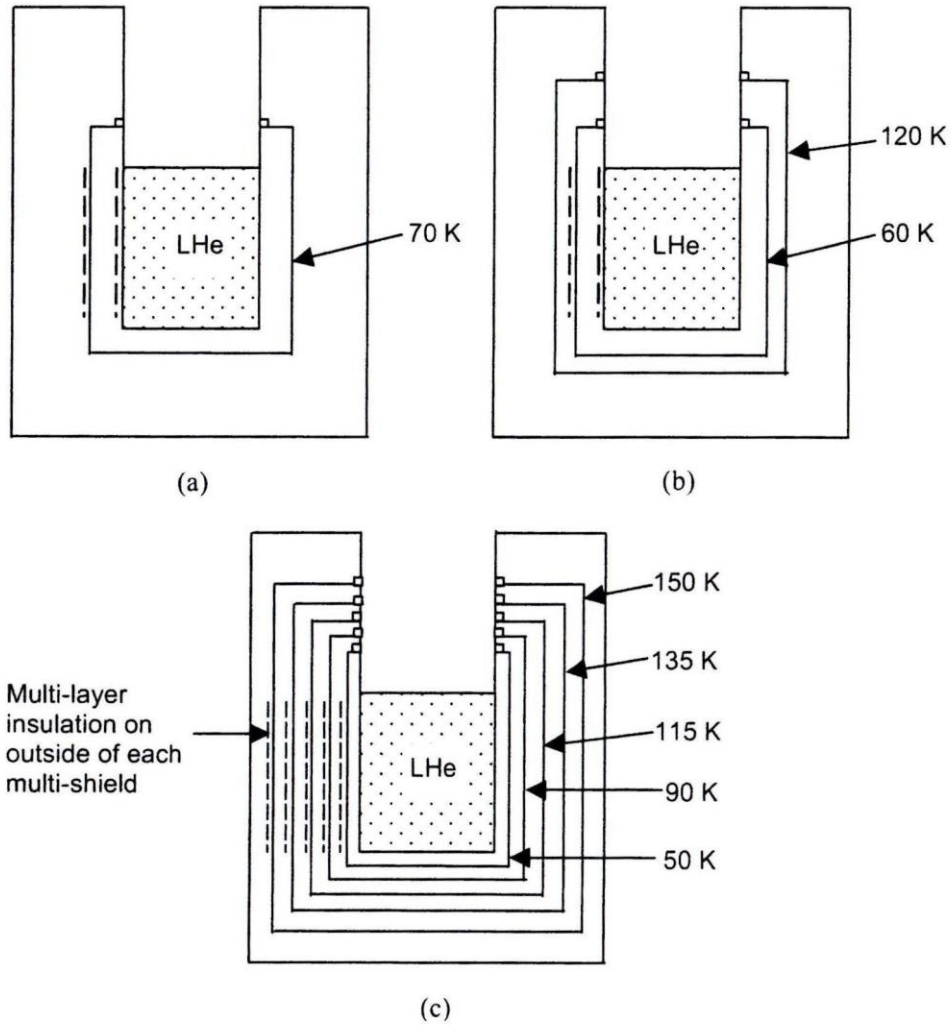
Liquid recirculation in storage tank



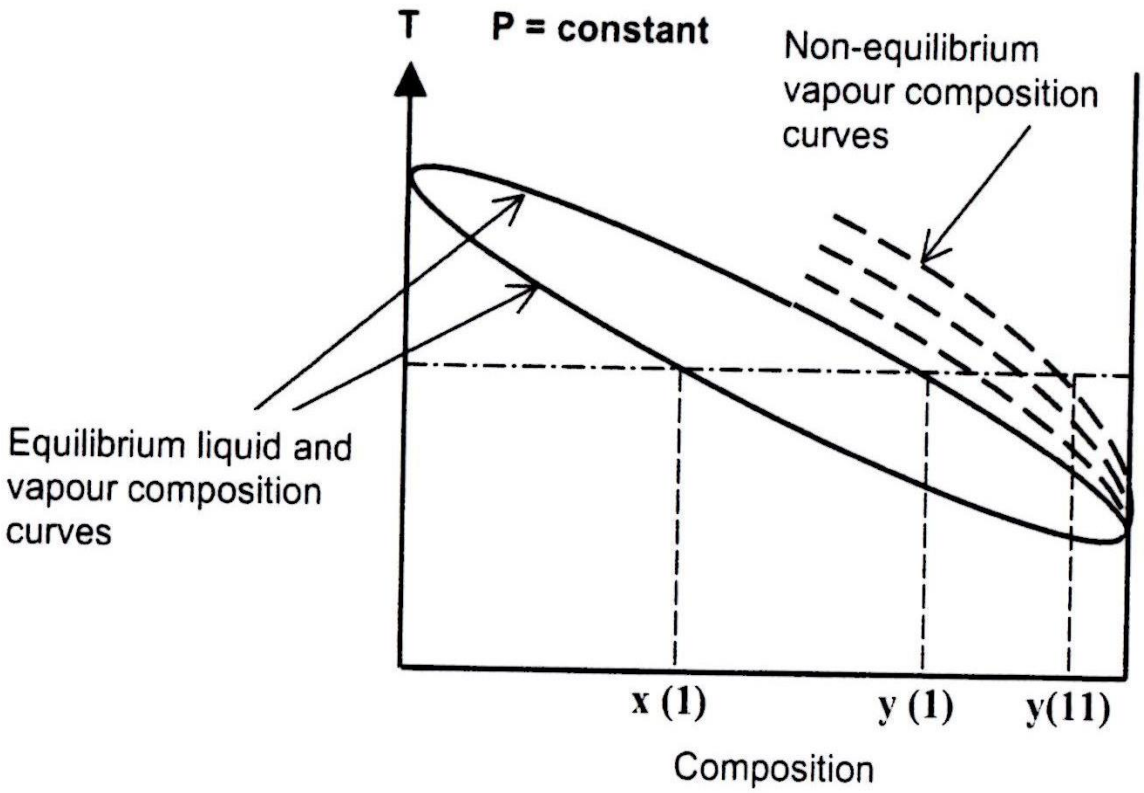
Vapour recirculation ratio of Mass flow / Boil-off mass flow



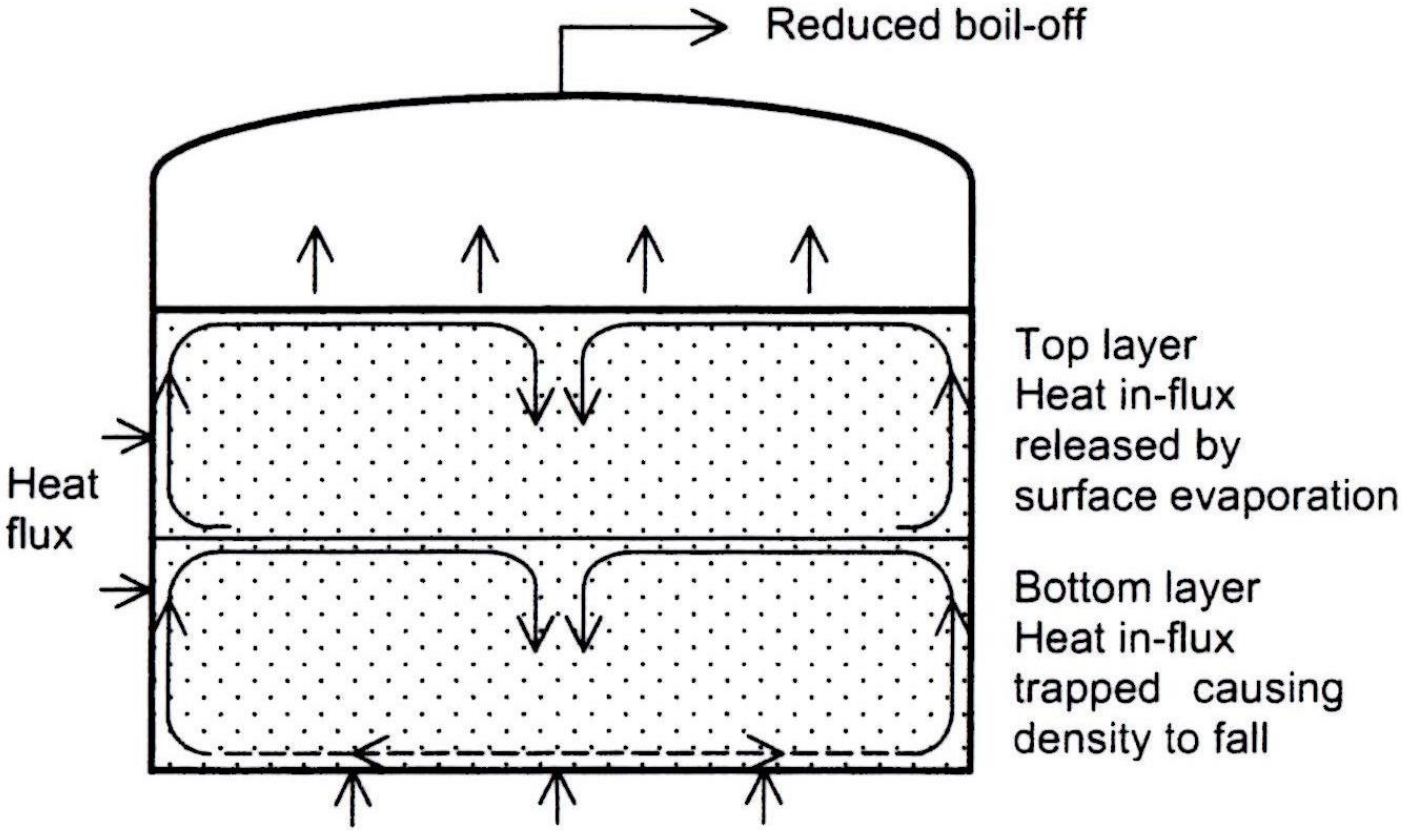
Multi-shielding for LHe containment



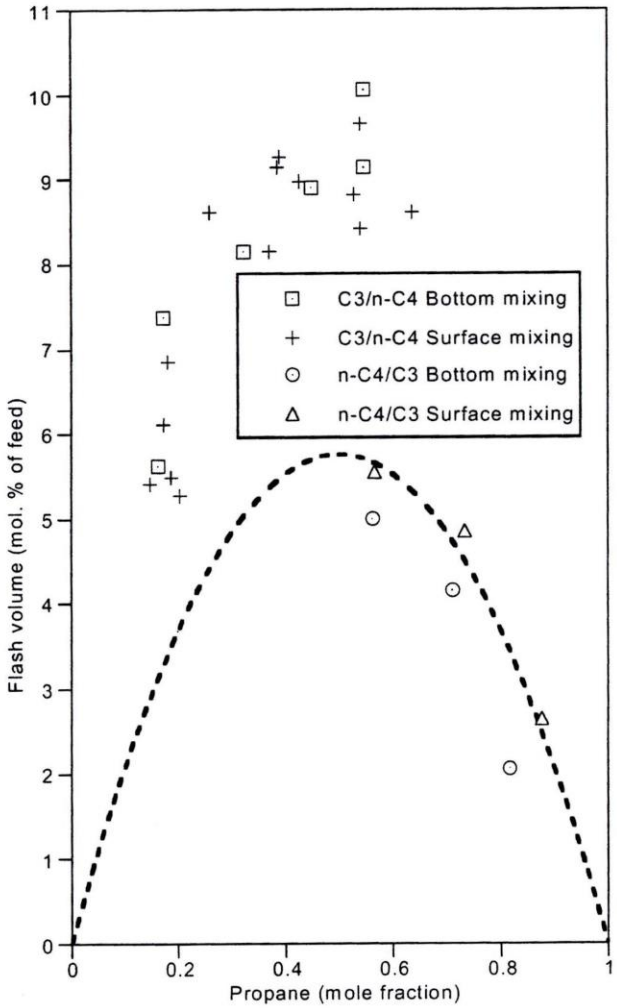
Typical vapour and liquid composition (T,x) curves during equilibrium (free boiling) and non-equilibrium surface evaporation



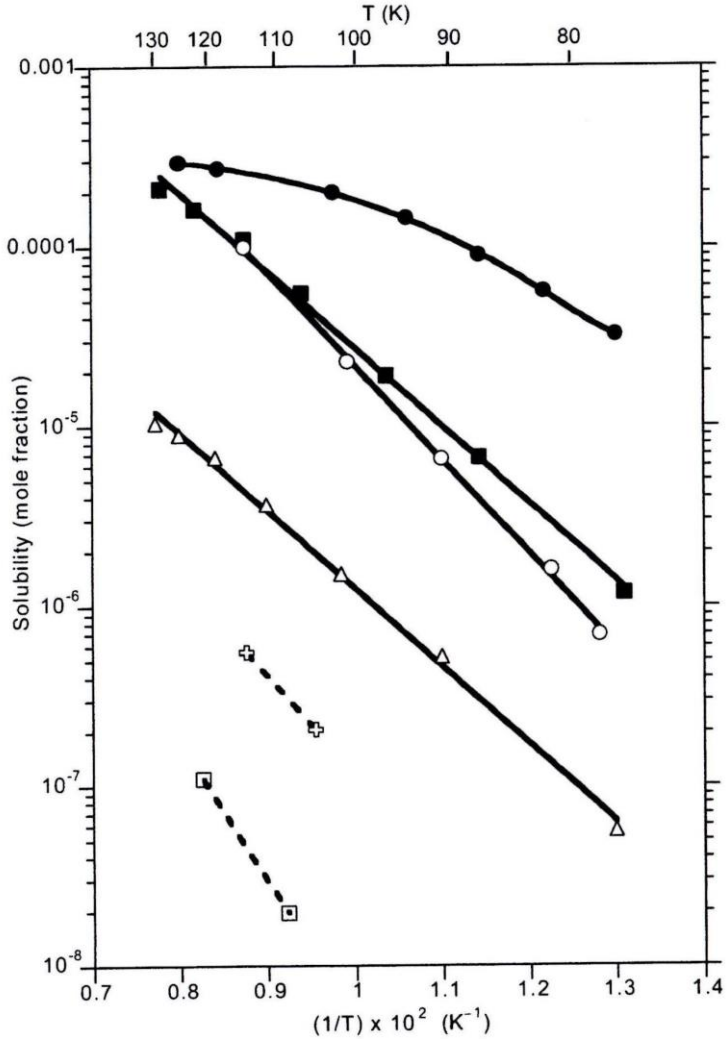
Stratification in LNG leading to Rollover



Differences in vapour flash between propane-butane and butane-propane mixing



Log S vs. 1/T solubility curves



Improvement in helium cryostat performance

Date	Duration	%age boil-off/ day
1955	6h	400
1965	100h	24
1975	100 days	1
1985	300 days	0.3
1995	1000 days	0.1

Examples of CryoFD applications

- **Tilted LHe cooled amplifier on Goonhilly radio aerial for first trans-Atlantic TV trials via Telstar satellite in 1962.**
- **Doubling cooling power of cryocooler/condenser with no change in compressor, with Cryomech.**
- **15 kA current leads with 1W heat leak at 4.2K for LHC.**
- **All the year round LHe at the South Pole from 2001.**
- **100 fold increase in reboiler/condenser heat transfer rates for Air Separation Units.**
- **Safety of pressurised LNG as road transport fuel.**
- **Cryogenic liquids for high density energy storage between renewable sources and AC power grid.**

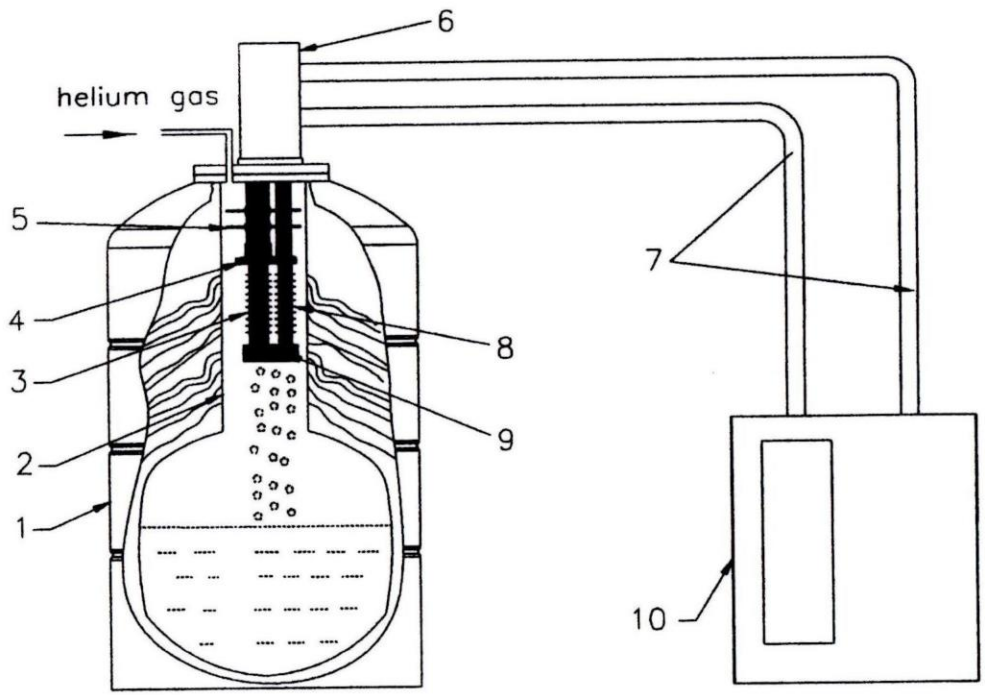


Fig. 2. Latest helium liquefaction system with pulse tube cryocooler. 1. helium dewar; 2. dewar neck; 3. fins on the 2nd stage regenerator; 4. 1st stage cooling station; 5. radiation shields/fins on the 1st stage regenerator; 6. pulse tube cold head; 7. flexible lines; 8. fins on the 2nd stage pulse tube; 9. 2nd stage cooling/condenser and 10. compressor.

On the road: European NGV fleet numbers are rising

Conclusions

- CryoFD for development of “Green Cryogenics” with minimum energy and liquid loss rates; also use of cryogenic fluids for energy storage between renewable source and electric grid.
- Effective use of sensible heat of cold vapour from NBPs up to 300K with no visible frost.
- Use the enhanced heat transfer rates across horizontal isothermal planes; also in vertical flows such as liquid and vapour boundary layer flows, and falling liquid film flows;.
- Much research needed to establish correlations for computer modelling from today’s concepts.